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Mechanical Characterization of Green Composite Brake Pads Reinforced with Coconut Shell Waste

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Abstract

In the present work, coconut shell powder proposed as a replacement material for the eco-friendly brake linings. The composites for brake pad were developed with other sizes of the coconut shell particles, namely (200 µm, 300 µm, 400 µm and 500 µm) The developed samples were evaluated for morphological, mechanical, physical and worability properties. The SEM micrograph proved that the coconut shell particulates are well dispersed in the composite everywhere and also shows good interfacial adhesion between reinforcement and resin. The attempted brake pads were densified measured, hardness tested, compressive strength extruded via a pin-on-disc tribometer for wear analysis. Its thermal stability and fade and recovery performance were also studied. The wear mechanisms as well as the performance of interfacial adhesion were also characterized by SEM after examination. The optimum coconut shell content identified that enhanced surface hardness, compressive strength, wear resistance and retained a low stable coefficient of friction irrespective of the service parameters. The superior performance was ascribed to good interfacial adhesion of the coconut shell particles with the resin matrix, leading to higher durability and lower wear loss during braking. In general, the results obtained confirm coconut shell powder as a low-cost and eco-friendly reinforcement to be used in NA braked applications, contributing for greener manufacturing practices by allowing the environmentally friendly re-use of agro-waste. In comparison to bigger particle sizes, the brake pad augmented with 300 µm coconut shell particles showed better hardness and a lower wear rate while retaining stable friction behavior. The study shows that turning coconut shell agricultural waste into a high-performing, ecologically friendly brake pad material is feasible.

Keywords: Brake pad, Asbestos, Automobile, Natural materials, Composite materials

INTRODUCTION

The brake system as a mechanical component is of essential significance for vehicles and equipment, such as industrial machines, etc., to transfer the kinetic energy into heat energy by friction. Brake discs are used to a greater extent than ever before in automotive applications these days. A disc brake system works by applying a FM in the pads to slow or stop motion. An ideal friction material should exhibit: High temperature stability, Low wear rate, Low noise (both under normal and heavy braking), A good but consistent CoF.

Brake pads Asbestos has been used in brake pads since the beginning of the 20th century, although its use as a friction material was not patented there until 1907. But as a human carcinogen, and one with health risks, the EPA restricted its use. Copper, semimetal ferromagnetic material, began to be considered as an alternative in the last twenty years but many of the industrialized countries have already begun limiting its use and it is expected that by 2025 copper will be fully banned [1]. The

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development of alternative materials to those commonly used is increasingly becoming an industrial focus worldwide, since friction materials are well-recognized as key components for the operation of braking systems.

Due to the ongoing development of materials light in weight and high strength has been conducted into metallic, semi-metallic and low metallic as well as composite materials for braking application. Traditional friction composites may contain 15 or more different components such as fibers, active fillers, inert filler and binders that lead to potential environmental risks [2]. So the application of environmentally friendly and renewable materials as friction part has become one positive option. In such respect, a new and environment-friendly alternative for disc braking application may be represented by coconut shell based friction material, presented in the current work.

Various scholars have studied brake pads made of tire pyrolytic carbon, alternative waste derived and composite materials. The wear rate and coefficient of friction for brake pads of CNTs from rice husk were modified with AgNPs under optimal conditions were approximately 2.15 mg/m and 0.42, respectively [3]. Other natural and industrial waste materials like silicon, bagasse, fine brass fibers and periwinkle shell have been investigated for production of asbestos free brake pad [4]. Chandradass et al. [9] investigated the mechanical and tribological behavior of asbestos-free carbon fiber brake pads, which revealed that a carbon content of 10 vol.- percentage gave relative high wear rate together with low coefficient friction; but higher accretion layer was observed. % resulted in Coefficient of friction, Tensile strength, flexural strength reduction and wear improvement. Sagiroglu and Akdogan utilized blast furnace slag as a modifier in polymer brake pads and observed that with 50% of the addition of slag, increase in coefficient of friction to 0.45.

More research is on surface modified brake pads: grinded gray cast iron pads coated with Stellit were used to protect against corrosion. The scale enhanced corrosion resistance by acting as a passive layer of cobalt and chromium oxide [11]. However, the high incidence of particulate matter (PM) emissions from brake pads continues to be a serious concern due to its detrimental effects on both human health and the environment. The use of the LPB-HCM showed potential for triboactivated basalt particles against steel balls [5]. Parent materials studies on rice husk and rice husk ash slides indicated that a friction material from 6 to 12 wt. % RHA showed a significant decrease in PM emissions and wear rates [12].

By using cashew friction dust, copper and asbestos-free brake pads were also formulated with various mixed of modifiers in an attempt to improve thermal stability. Of the composite formulations tested, it was revealed that boron-graphite-modified brakes have improved physical, mechanical and tribological properties when compared to those of furfural [1]. When excess amounts of cement bypass dust and barium sulfate are used as fillers, researchers found that friction coefficient initially increases but decreases at higher concentrations [13]. More recently, barite powder and kaolin clay were used to create ceramic matrix composites.; as a result better friction and wear behavior was observed for barite-based composites than kaolin based ones [14].

Other investigations have studied fibers with iron and graphite powders as reinforcements and reported that the best frictional performance was obtained for 20 wt% of iron and 14 wt% of graphite [15]. Mullite and kyanite containing copper matrix friction materials were studied, wherein the presence of kyanite resulted in formation of a protective tribofilm, exhibiting 30%less wear at a concentration of 1%. Environmentally friendly brake pads reinforced with Aramid fiber/pulp and Zylon fibers were also prepared, hydroentangled eens getting a higher coefficient of friction than that based on brake paste derived from Aramid [2,16]. In addition, wear models for laboratory asbestos- and copper-free brake pads have been formulated with test vehicles and validated [17].

The impact of particle size on combined mechanical, tribological, and fluid absorption behavior has received little attention, despite the fact that numerous research have investigated agro-waste materials for brake pad applications[25-27]. By methodically assessing coconut shell powder in the 200–500 µm range, the current study fills this gap and offers insights into the ideal reinforcing properties for environmentally friendly brake pad applications. Figure 1 shows an Overview of Alternatives to Asbestos-Free Brake Pads and Related Materials

In spite of these advances, those conventional synthetic friction materials in the form both organics and inorganics still have adverse health and environmental effects. In addition, only few attention had been paid to the experimental validation at real vehicle load.

A new asbestos free disc brake pad material with coconut shell as a base have been developed in the present work. Coconut shell powder of 200–500 µm average particle size was used to prepare brake pad composites, and their morphology and tribological behavior were studied. The best of these coconut shell brake pads were also tested in the front wheelof a test vehicle at mild and severe braking. The knowledge seeks to help other researchers of braking materials to design sustainable automotive materials in order to build up for a cleaner, safer, and ecologically favorable friction.

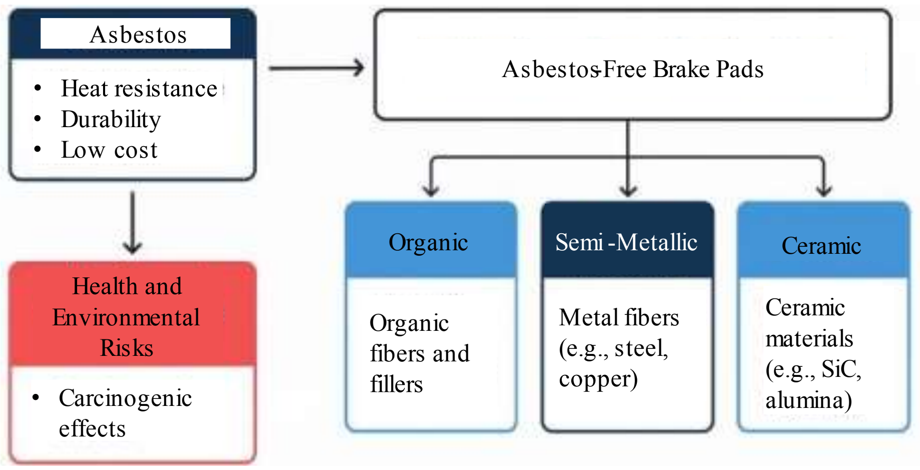

Figure 1. An Overview of Alternatives to Asbestos-Free Brake Pads and Related Materials

Increasing requirement of asbestos-free brake pads has implied the use of various alternative materials with satisfactory performance to compete some dusting and environmental problems [7]. These materials consist of organic, semi-metallic and ceramic-based compounds each with their own unique properties and limitations in coefficient of friction (COF), wear rate, thermal conductivity and noise [8].

Prior research on agro-waste reinforcements such periwinkle shell, bagasse, and rice husk mostly examined wear and friction behavior in lab settings. Particle size optimization, fluid absorption behavior, and interfacial bonding mechanisms, which are thoroughly covered in this paper, have, however, received little attention.

Organic These pads are generally very easy on the discs and always deliver a smooth brake operation with no or minimal noise, but they do not have the same life as semi-metallic and ceramic compounds, and low thermal conductivity compared to semi metallics or ceramics. Such pads typically are highly loaded with resin fillers which include fibrous organic materials. Semi-metallic Semi-metallic brake pads are brake pads with some metallic ingredients mixed in with other elements. But, they're typically harder on brake rotors and can be noisy when in use.

The ceramic pads, the braking material is made of silicon carbide (SiC) and alumina which can provide high temperature stability, low wear resistance and always keep stable friction performance.

These properties render ceramic pads especially useful in high performance and severe driving applications [9]. Proper material selection and their combination are the key to maintain a trade-off of braking performance, durability, environmental impact and cost.

In the context of environmental friendly brake pad, a few works have been reported on developing sustainable brake pads using natural fibers and agricultural waste as replacement of synthetic constituents [10]. It has been claimed that the coefficient of friction as well as wear behavior are primarily dependant with the chemical units and microstructure of brake pads [11]. Table 1 shows Technological Developments in Brake Pads Without Asbestos

Ceramic/matrix composites are being increasingly considered for automotive applications especially for components with high mechanical properties and thermal stability [12]. These components can be developed with low weight and have desired properties like high specific strength, with a stiffness, hardness, wear resistance property second to none (much higher than fine-grained alloys), improved thermal conductivity (low temperature), high energy absorption capability at ambient temperatures, small coefficients of friction for polymers resulting in self-lubrication compounds and low thermal expansion rates [13].

Table 1. Technological Developments in Brake Pads Without Asbestos

Category	**Literature Context**	**Materials / Technologies**	**Performance Characteristics & Impact**
Historical Usage	Asbestos was extensively used in brake pads for more than eight decades due to its low cost, high thermal resistance, and excellent tensile strength, which made it a suitable friction material in early braking systems.	Naturally occurring asbestos mineral with favorable mechanical and thermal properties.	Provided stable friction and long service life; however, its use posed severe health risks.
Health & Environmental Concerns	Long-term exposure to asbestos was found to cause serious health conditions, including lung cancer, mesothelioma, and asbestosis, leading to regulatory bans in many countries.	Government regulations, environmental policies, and public health initiatives.	Accelerated the global transition toward safer, environmentally sustainable, and non-toxic brake pad materials.
Material Alternatives	In response to asbestos restrictions, brake pad formulations evolved toward organic, semi-metallic, and ceramic-based composites, as widely reported in recent literature.	Organic fibers, steel wool, copper, silicon carbide (SiC), alumina, natural fibers, agricultural waste materials, and ceramic matrix composites (CMCs).	Each material system offers distinct advantages and limitations related to friction stability, wear resistance, noise generation, and thermal performance.
Advanced Materials Focus	Recent research increasingly emphasizes ceramic matrix composites (CMCs) for high-performance braking applications due to their superior mechanical and thermal properties.	Carbon fiber–reinforced SiC and tailored ceramic composites with optimized microstructures.	Lightweight, high wear resistance, excellent thermal stability, and low thermal expansion, making them suitable for high-end and performance-oriented automotive systems.

Health Hazards of Asbestos-Based Brake Pads

Since asbestos-containing air suspension particles in conscientiousness causes asbestosis, mesothelioma and lung cancer. Those working in the brake manufacturing, auto repair, or brake maintenance are at higher risk as they come in direct contact with asbestos fibers that are released during the process of braking mechanism while they install or service them. Emerging scientific knowledge of these dangers has resulted in stringent regulations on the application of asbestos in automotive parts.

Regulations such as the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) law in Europe and the Occupational Safety and Health Administration (OSHA) regulations in the United States have made it necessary to drastically lower exposure limits and, in many cases, to completely discourage use. These protections have been key in protecting worker's health, and minimising environmental contamination. Figure 2 Major health risks due to asbestos-based brake pads and the important regulations used for managing their use are depicted in Figure 2.

The universal ban on asbestos in brake systems is the result of the very poor health effects produced by inhaling its fibers. The two most commonly studied outcomes following exposure are: asbestosis (chronic lung disease resulting from prolonged inhalation of fibers), mesothelioma and lung cancer related to asbestos. Without the protection of proper measures, automobile repair shop staff, brake factory workers and even those just changing their own brakes are at an increased risk.

Due to these concerns, regulatory restrictions have been put in place around the world that restrict or ban asbestos use in friction materials. Workplace exposure limits are still regulated by OSHA in the United States, and legislation like REACH have led to a near total ban on asbestos-containing products throughout the European Union. Together, these regulations have hastened the pace of non-asbestos brake pad material advancement and utilization. The move to safer alternatives has resulted in the minimization of occupational hazards but is also consistent with broader public health and environmental protection goals.

Figure 2. Asbestos-Based Brake Pad Health Risks and Regulatory Measures

In addition to the well-reported risks for health, processes of asbestos canvassing, mining and production carry also significant consequences on the environment. Asbestos mining commonly causes habitat destruction, soil erosion, and produces enormous water and air pollution. In addition, the disposal of asbestos-containing brake pads poses significant environmental challenges to industry, as when cutting operations, wear or disposal occurs a substantial quantity of respirable fibers are loosened into the air. The long-term management of asbestos is especially challenging because it persists in the environment and can resuspend into the air through natural weathering or human activities. As a result, the environmental impact of asbestos is huge and urgent for sustainable and ecologically friendly alternatives are called for.

Worn brake pads and other asbestos waste can be deposited in soil and water systems resulting in long term contamination. To minimize such risks, a number of countries have established dedicated disposal sites with containment and protective lining that aims to ensure the fibers do not get released. However, increasing market uptake for asbestos-free brake pads represents an effective means to limit the environmental impact of the automotive industry and to promote environmentally sound transport systems.

Asbestos brak epads have been replaced with non-asbest os materials which has also sp urred ma terial developments. Asbestos-free brake pads in general today can be divided into three main types of materials (semi-metal, non-metal) namely metallic-organic-based and ceramic-based; each has its own pros and cons concerning coefficients of friction, wear characteristics, noise generation potential and thermal conductivity. Pad compounds wearing varying percentages of steel fibers, abrasives and graphite, semi-metallic pads offer an even greater durability and better resistance to edge chipping. But these advantages are often paid for with more brake noise, elevated rotor wear and dust generation -- especially under high speeds.

LG All-organic non-metallics are made up of various organic fibers. (usually glass, resin or rubber based) and resins and friction modifiers. These pads provide excellent stopping power and don't squeak, they have outstanding pad wear and less rotor wear. Nevertheless, their inferior thermal conductivity can also prevent high-temperature or heavy-load braking performance. Ceramic fibers, friction modifiers, and binders are embedded in a resin matrix to create ceramic brake pads, which offer trade-offs between performance attributes including reduced noise generation., low rotor wear rate and stable friction response over a wide temperature range [14].

The components utilized to create asbestos-free brake pads must appropriately address the applications performance requirements, its durability goals and effects on environmental [6]. Here also the recent study has shifted towards the development of advanced composites, more precisely natural fiber composites (NFC's) for sustainable environment. Brake pad composites enhanced with coconut shell particles have shown encouraging results. [15] and natural fibers for friction materials are attracting more attention as it is an environmental friend technology [16]. The use of biodegradable resins and natural reinforcements carries the dual advantage of reducing reliance on man-made materials and cutting down environment strain in terms of renewable sourcing and environment-friendly disposal [17].

Coconut shell particles has showed significant potential as bio-waste reinforcement for brake pad applications. It has been discovered that adding them enhances the wear characteristics, mechanical strength, and thermal stability of brake pad composites. Moreover, the coconut shell-based reinforcements has many merits as low costs, less weight, high hardness and strength; good thermal properties, less pollution and degradability compared to typical synthetic fillers [18]. Table 2 shows the health risks of asbestos-containing brake pads and recent progress in asbestos-free braking materials.

Asbestos-Free Brake Pad Materials

Significant R&D effort has been directed to identify alternative brake pad materials that are more durable, with improved performance and reduced environmental impact. Most of these studies have been motivated by the desire to remove asbestos from friction materials, while maintaining or enhancing the braking performance and safety characteristics. For this reason, much effort has been focused on the development of non-asbestos containing brake pads that are capable of achieving the necessary levels of performance (both in terms of performance requirements, legislation and environmental care) appropriate to modern times.

In the available replacements for those applications, semi-metallic brake pads are a high quality option that possess one of the best quality to performance ratios. Semi metallic brake pads are comprised

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of metal fibers. These fibers typically form around 30-65% of the pad by weight. These characteristics render semi-metallic pads very interesting for applications which demand high braking performance and heat resistance [19]. But their application is not free from drawbacks, such as additional noise and rotor wear, as reported in previous studies.

Table 2. Health Hazards and Advancements in Asbestos-Free Brake Pads

Category	Details	Materials/Technologies	Health Impact	Environmental Impact	Performance Notes
Health Risks of Asbestos	Exposure leads to asbestosis, mesothelioma, lung cancer; high risk to brake mechanics	Asbestos dust from traditional pads and linings.	Severe respiratory illnesses, chronic lung damage.	Long-lasting environmental fibers; hazardous disposal.	Effective friction but dangerous and outdated.
Regulatory Actions	Strict regulations imposed by OSHA and EU REACH on asbestos use.	Exposure limits, bans, and enforced workplace safety laws.	Reduces direct exposure risk to workers and public.	Discourages further use and waste generation.	Drives demand for safer, legal alternatives.
Environmental Hazards	Mining and disposal of asbestos causes pollution, habitat damage.	Airborne fiber release, toxic landfill accumulation.	Indirect public exposure from contamination.	Severe pollution and soil/water contamination risks.	Non-renewable, unsustainable lifecycle.
Material Alternatives	Organic, semi-metallic, ceramic brake pads replace asbestos- based pads.	Natural fibers, copper, steel, SiC, alumina resins.	Non-toxic, reduced risk of health issues.	Lower pollutant levels, safer disposal.	Vary in noise, wear rate, and friction; generally improved safety.
Bio-Based Innovations	Natural Fiber Composites (NFCs) explored for eco-friendly pads.	Coconut shell, biodegradable resins, glass fibers.	No toxic release; safe for human handling.	Biodegradable; minimal long-term pollution.	Good mechanical strength, wear resistance, low cost.

Figure 3 Material and processing types currently used in the production of non-asbestos based brake pads. Due to environmental and health issues linked to traditional asbestos-containing friction materials, extensive studies have been carried out to find potential alternatives at low cost and with sustainable properties. The literature reviewed classifies these alternatives into natural (agro- and bio-waste based reinforcement) and composite materials that are blended so as to produce specifically tailored tribological/mechanical performance using organic, metallic or ceramic components.

This categorization can serve as a structured knowledge for readers to comprehend the recent progress in development of asbestos-free brake pad materials and also reveals a trend towards both environmental-friendly and high-performance friction materials.

PRODUCTION OF BRAKE PADS MADE FROM COCONUT SHELL (CS)

Making Coconut Shell Powder and Producing Brake Pads

Adhering to sustainable and bio-waste-based trends friction materials outlined in the previous literature, coconut shell was chosen as natural reinforcement for asbestos free brake pad production. Coconut shells were bought from local markets and first cleaned for 30 min by using fruit washing machine to rid off impurities on the surface. The shells were soaked in hot water (50–55 °C) for 4–5 minutes and then cooled to room temperature in order to remove any leftover stickiness on the endosperm surface.

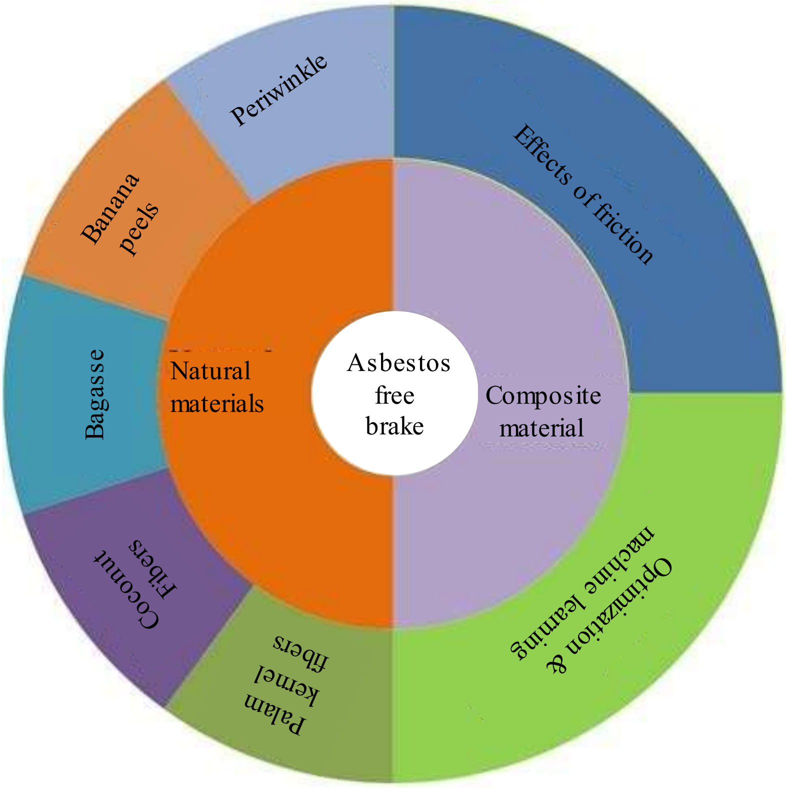

Figure 3. Categorization of Natural Materials and Composite Improvements in Asbestos-Free Brake Pads

To prevent moisture, the cleaned shells were dried using hot air at 70 °C for 15 minutes. The dried coconut shells were ground to powder by pulveriser. The resulting powder was a mixture of fine and coarse particles and this was sifted over a vibrating mesh screening assembly. Coconut shell powders in fixed particle size ranges were made using four distinct mesh sizes: 200 µm, 300 µm, 400 µm, and 500 µm. The scanning electron micrographs of prepared coconut shell powders with varying particle sizes are shown in Fig. 1(a–d).

Due to the high viscosity of the phenolic resin and other factors, the fully combined coconut shell powder in a suitable particle size of 200–500 µm with phenolic resin, together with additional filler materials like mica and barium sufate and stabilizers, should be placed in a Sigma mixer for 35–45 minutes. The viscous dough like mass obtained was spread uniformly on a trough and sun dried for about 3 hours so as to eliminate the moisture content.

After that, the intended shapes were pressed out of dry mixture by pressing them under pressure of 80 bar and at temperature of 120 °C (PVC sheets were utilized to avoid material adherence to die surfaces). The brake pads were then cooled to room temperature and cut to size. The resulting samples were then tested to verify the absence of asbestos and further characterized.

An overview of the entire preparation process for the brake pads is shown schematically in Fig. 4. This systematic preparation and fabrication method not only guarantees the same materials between samples, but also enables a reliable comparison on the mechanical and tribological response as described in thus following sections.Fig.5 shows the Coconut shell brake pads process

For each test condition, three specimens were evaluated, and the reported values represent the average of the measurements. Hardness testing was conducted in accordance with ASTM D2240, while wear tests were performed using a pin-on-disc tribometer following ASTM G99 standards.

Figure 4. Images of 400 µm, 300 µm, 150 µm, and 100 µm CS powder

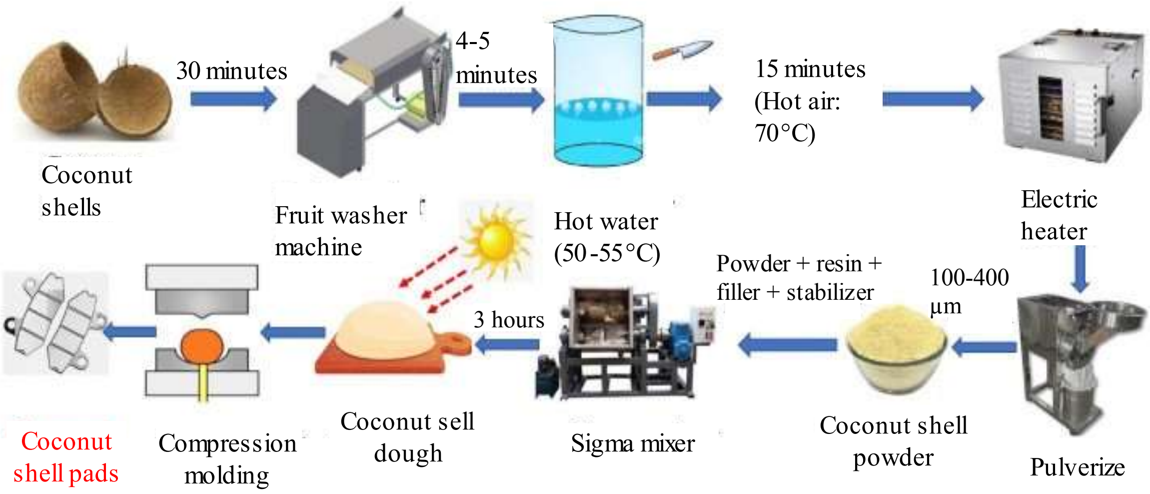

Figure 5. Coconut shell brake pads process

CS Pad Characterization

Following manufacturing, the coconut shell (CS)-reinforced brake pads' mechanical, physical, and tribological characteristics were methodically assessed to look into their possible applications as a brake pad material. In the course of performance study, also morphology and surface features of manufactured pads were analyzed to understand the material gradient pattern and interfacial behaviour in composite.

SEM (SU6600, Hitachi, Japan) was used to examine the brake pad samples' morphology. To improve surface conductivity and prevent charge during imaging, the samples were sputter-coated with gold prior to SEM analysis. This analysis allowed detailed examination of particle distribution, interfacial bonding and morphology induced by some fabrication process and further testing.

To assess the CS brake pads' resistance to water and oil absorption, soaking experiments were conducted. Prepared pads were soaked in a solution of SAE 20W–50 engine oil and water over the course of one day at room temperature ranging from 27 to 30 °C and swelling behavior was evaluated by comparing weights as well as dimensions between before and after the immersion. Such measurements were valuable for determining the dimensional stability of the material as well as its fluid-absorptivity under service-like conditions.

Because the built up brake pads did not have perfectly regular geometries, the bulk density was measured according to Archimedes principle. Each sample was weighed in air and its actual weight (Wa) recorded, after which it was submerged in water to record its apparent weight (Ww). The displaced water (Vw) was calculated based on Equation (1), and the brake pad bulk density (ρ) was then obtained from Equation (2). That way, they can estimate density properly and be compared to regular brake pad materials.

The detailed characterization techniques applied in this study initialize a valid correlation between material composition, microstructural features and performance properties for the treated materials as addressed in the results and discussion sections.

$$V_w = (W_a - W_w) / (g.\rho_w) \tag{1}$$

$$\rho = (\rho_w . W_a) / (W_a - W_w) \tag{2}$$

Where g and w are the gravitational acceleration and density of water.

RESULTS AND DISCUSSION

Microscopy Characterization on Coconut Shell Reinforced Brake Pad

The surface topography of brake pad composites reinforced by CS powder with various particle sizes (200 µm, 300 µm, 400 µm and 500 µm) is displayed in Figure. 6. Particle distribution Scanning electron microscopy (SEM) micrographs show that CS particles are distributed generally homogeneously in the phenolic resin matrix, which is a sign of an efficient mixing and good interface adhesion between reinforcement and the matrix [20–24]. Use of Sigma mixer in the preparation process was vital for uniform dispersion of all the contents throughout the composite.

Further observation of the SEM images (Figure. 6a-d) demonstrate different microstructural responses depending on CS particle size. Composites reinforced with finer CS particles (200 µm and 300 µm) show a more homogeneous and compact microstructures than those reinforced by larger particles (400 µm, 500 µm). This better dispersion may be due to the larger specific surface area of finer particles, promoting interfacial contact and adhesion between CS powder and resin matrix.

Increased hardness and wear resistance are directly dependent on the stronger interfacial bonding in composites with, finer particle sizes. Moreover, the stronger bonding is responsible for a lower risk of particle pull out during sliding friction and contributes to the higher tribological performance. However, the higher strength of composites with coarse CS particles may not occur by their assisting in improving of dispersion on account of nonuniformity distribution pattern, which possible will generate weak interfacial region and the local stress concentration. Such discrepancies at microstructural scale can detrimentally affect the load-carrying capacity and lead to poor tribological outlets under braking condition.

In general, microstructures exhibited SEM analysis affirm that brake pads enriched with smaller powdered sizes (200Â µm and 300Â Âµm)agreeably developed better features facilitating improved mechanical resistance and tribological performance properties. These results are in general agreement with previous observations recorded in literature and demonstrate that, particle size coupled to interfacial bonding play influence on the performance of composite braking materials.

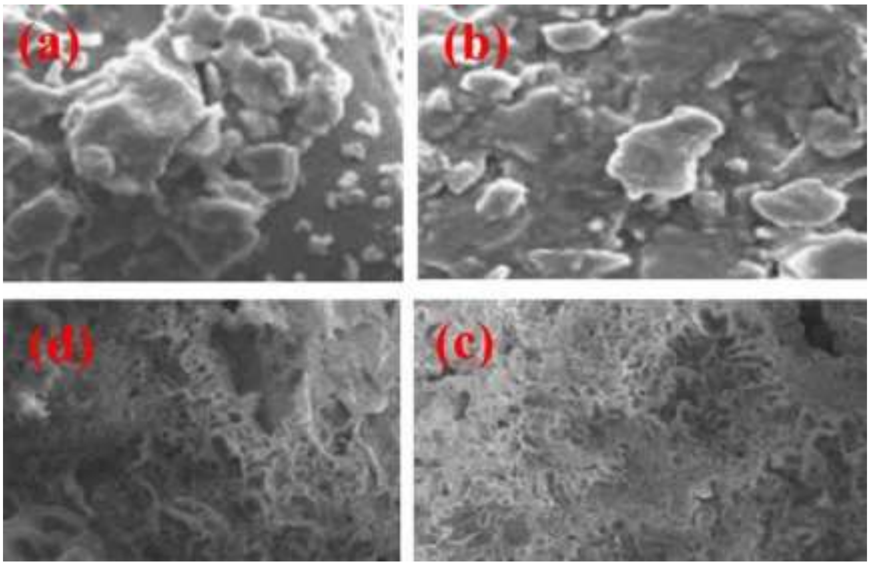

Figure 6. CS pads with powder sizes of (a) 500 µm, (b) 400 µm, (c) 300 µm, and (d) 200 µm are displayed in SEM images.

Water and Oil Absorptivity of CS Brake Pads

A brake pad's braking efficiency depends heavily upon its water and oil soak resistance. Over-absorption may cause swelling of the material and dimensional instability, with an adverse effect on friction characteristics, affecting brake efficiency. Thus, the behaviour of brake pad materials in various fluid media is important for determination of their long-term durability and performance.

Figure 7 compares the thickness variation of CS reinforced brake pads with different grain sizes before and after immersion in water and engine oil SAE 20W–50. The data exhibit significant lower water and oil uptake values for CS filled composites with 200 µm (and smaller) size particles, as compared to those containing 500 µm CS particles and of course to the ABS matrix: This behavior is related to better adhesion between the polymer matrix and refined particulate reinforcing structures showing a less porous nature. Smaller CS particles have greater specific surface area so that they have more opportunities to contact the resin matrix and get impregnated during fabrication, which in turn restricts the penetration of fluids.

Water and oil absorbing resistance, of all examined CS particle sizes in brake pad are quite similar and for both water and oil absorption, treatment with 300 µm CS powder showed the lowest performance among these three treatments. Pads with 200 µm particles also performed well, but the 300 µm composites proved superior across all compositions. This behaviour may be attributed to an optimum particle packing density and resin adhesion, thus reducing the voids and promoting a reasonable load transfer.

The swelling behavior noticed post-soaking is mainly attributed to composite matrix wetting and the partial relaxing of compaction-induced compressive stresses during shaping. It is interesting to observe that all the CS composites have only a small change in dimension after immersing them into either water or engine oil. The dimensional stability is an indication of the high resistance to fluid-entrained degradation and confirms that coconut shell–reinforced brake pads are wear-resistant, shape-stable, and environmen- tally friendly materials for application as brake pads.

The improved wear resistance found for the 300 µm CS-reinforced brake pad can be due to enhanced interfacial bonding and reduced porosity, which prevent particle pull-out during sliding. Although the current work shows greater stability under fluid exposure, similar results have been documented for agro-waste-reinforced composites.

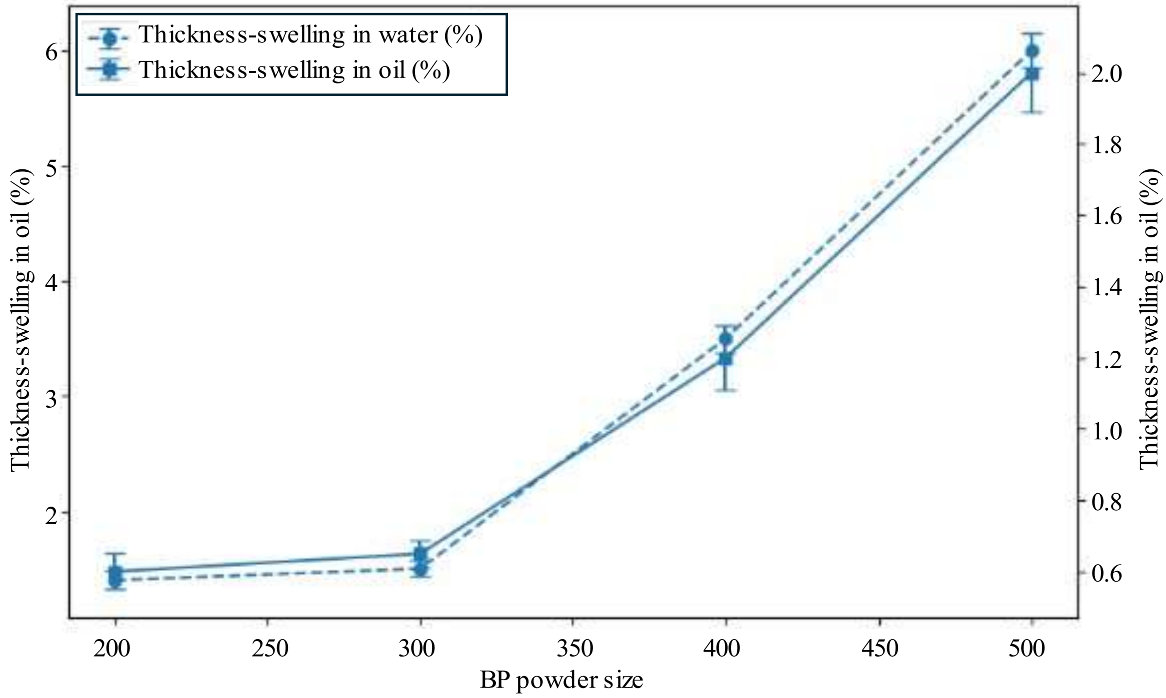

Figure 7. Coconut shell pad thickness in motor oil and water

CONCLUSION

- In this work coconut shell has been suggested as an ecofriendly and efficient reinforcement material for non asbestos-based brake pad which will overcome the health and environmental issues related to conventional. Brake pads were made to practical requirements from coir dust at a range of particle sizes, indicating that waste can be utilized for high performance brakes of motor vehicle.
- The effects of particle size of coconut shell (200-500 microm) on the mechanical and functional properties were studied systematically in brake pads. Short-term and long-term tests were performed to evaluate the feasibility for practical use and durability of the composites. The experimental findings demonstrate that the performance of the brake pad is significantly impacted by particle size.
- Morphologic characterization obtained by scanning electron microscopy (SEM) demonstrated well distribution of the coconut shell particles in the resin system, This shows that the reinforcement and matrix have high interfacial adherence. Additionally, the composite brake pads' mechanical stability and load transfer were improved by this homogeneous microstructure.
- While the present study demonstrates promising laboratory-scale performance, further investigations under high-speed braking and full-scale vehicle testing are required to validate commercial applicability.
- Brake pads performed better in absorbing water and oil due to their reduced particle size and fluid resistance. 300 µm coconut shell particle-reinforced brake pads already demonstrated the best performance among the formulations examined under a degree of compromise intended to enhance both interface bonding and particle pack density. Overall, the findings showed that brake pads loaded with 300 µm particles from coconut shells.

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